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14. ABSTRACT
This project aims to demonstrate the feasibility of miniature, inexpensive, in vivo robots to provide basic diagnosis and triage in military environments. This work comprises the first phase of a two phase project. The first phase focuses on the design and construction of an in vivo camera robot. The robot will be designed to be fully inserted into a patient and, in a future project, tested in patients. The robot will return live in vivo video images that allow the surgeon to explore, diagnose, and stabilize the patient while geographically separated. Several functional prototypes capable of tissue manipulation, abdominal exploration, and surgical utilization have been developed. This revolutionary, robotic technology has demonstrated its applicability in natural orifice and single incision minimally invasive surgical procedures. Such innovative procedures are virtually impossible to perform without the design and creation of new tools like our miniature robots. Successful completion of prototype development is a critical first step toward our ultimate objective, development of a group of in vivo robots that can provide diagnosis and therapeutics, as it builds on previous successes and focuses on developing an image-guided robot capable of provisions of basic triage in forward and traditional healthcare environments.

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robotic telesurgery, in vivo robot, triage in forward environment, remote first responder, laparoscopic surgery

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Introduction

This project aims to demonstrate the feasibility of miniature, inexpensive, in vivo robots to provide basic diagnosis and triage in military environments. This work comprises the first phase of a two phase project; the first phase focuses on the design and construction of an in vivo camera robot. The robot will be designed to be fully inserted into a patient and, in a future project, tested in patients. The robot will return live in vivo video images that allow the surgeon to explore, diagnose and stabilize the patient while geographically separated. The second phase of this project focuses on continued animal trials as well as human testing and regulatory approval. Our long-term objective is to create a group of in vivo robots that can provide diagnosis and therapeutics at all echelons of military medical care.

Body

Task 1: Development of a small in vivo vision system

Planar Manipulator Robot

Work has been directed towards the automation of surgical tasks using the planar manipulator robot [1]. Such tasks could be useful in situations where the patient is in a location far from a trained surgeon. A surgeon at a remote location could control the robot even if the communication link between the surgeon and the patient is of low bandwidth or has high latency. The robotic system has three main components including a visual tracker, controller, and stereovision. The surgeon is presented with a video capture from the robot and then selects a point on the image for the robot to move to, such as a piece of tissue to grasp or cut. Using a stereo correspondence algorithm, the location of the point is computed in 3D space. The user then verifies the computed point, and the controller moves the end effector to the desired position. This method has been demonstrated in several benchtop tests using the robotic system. In these tests, a piece of rubber band was placed in a mount in the middle of the robot's workspace to simulate a piece of tissue.

Full Mobility Manipulator Robot

The primary challenge with the design of a full mobility robot is meeting the competing design constraints of speed, size, and force. For the initial prototypes of the complete robot, the speed and force constraints were met at the expense of size. The first full mobility robot, NB2.0, was designed and built [2]. The complete robot platform includes an in vivo robot and a remote surgeon interface console. The robot design consists of a left grasper and a right cautery forearm, each connected to a central body at a shoulder joint link. For this robot, the yaw and pitch degrees of freedom are located at the shoulder joints, and the roll and translation motions are part of the prismatic elbow joint. The body of the robot is fitted with a collar that is used with an external support assembly for fixation and gross positioning of the robot. For this prototype, a standard laparoscope is mounted to the support shaft to provide lighting and visualization. The surgeon control interface is located remotely within the operating room and consists of two controllers, a video display, and a foot pedal, as shown in Figure 1. This robot has been used to perform a cholecystectomy in a non-survival animal model procedure. For this procedure, a large incision was used for insertion of the robot due to the size of this initial prototype. The improved dexterity and speed of this robot better enabled tissue dissection. This robot has also been used in cooperation with the Compact Bevel-geared Robot for Advanced Surgery (CoBRASurge) to perform surgical tasks in a non-survival animal model [3,4].

Figure 1. Surgeon interface for manipulator robot.

Additional prototypes have been designed and built. The design of these robots is similar to the previously discussed full mobility manipulator robot, but with a one degree-of-freedom rotational elbow joint instead of a prismatic joint, as shown in Figure 2. These changes have increased the dexterous workspace of the robot, while also maintaining sufficient strength and speed. The forearms of this robot were also designed to enable the end effectors to be interchanged depending on the particular tasks being performed. For example, during a cholecystectomy, a cautery and a grasper forearm are used. Then to perform knot tying, the robot could be removed and the cautery end effector replaced with a grasper. These robots have also been used in animal model studies to successfully perform two cholecystectomies. Similar to the initial prototype robot, these robots were also supported using an external assembly mounted to the surgery table, and the robot was inserted through a large abdominal incision. Continuing improvements to this robotic platform are focused on reducing the size of the robot, incorporating on-board lighting and cameras, and introducing an additional degree of freedom at the wrist of the robot.

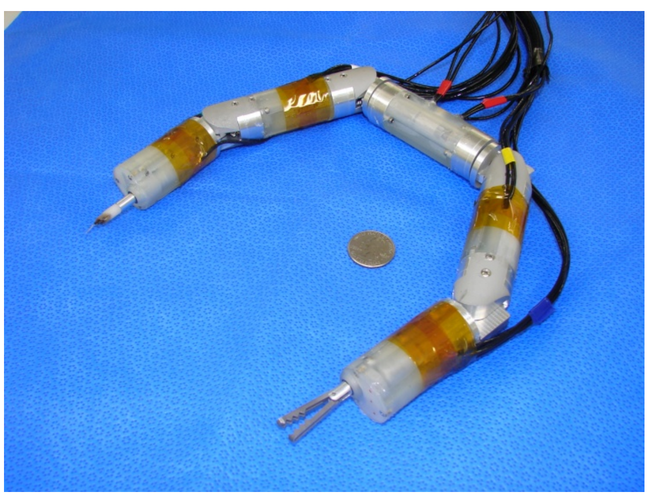

Figure 2. Dexterous manipulator robot (NB2.0) with rotational elbow joint.

For more recent multi-functional robots, the kinematics were modified to allow for a greater dexterous workspace, as in the NB2.1 [5]. This robotic platform is designed specifically for Laparoendoscopic Single-Site Surgery (LESS), and consists of a multi-functional robot and a remote surgeon interface. This robot is designed to be inserted through a single incision and be contained completely within the peritoneal cavity. The miniature dexterous *in vivo* robot, shown in Figure 3, consists of two arms connected to a main body segment. The main body of the robot is composed of three modules. These modules can be independently inserted through a single incision and then assembled once inside the peritoneal cavity to provide surgical capabilities. Following assembly of the robot, a mounting rod is introduced through the insertion incision and mated to the center module to support the robot within the peritoneal cavity. The mounting rod is supported by an external support system that is mounted to the rails of the operating table. Gross positioning of the robot within the peritoneal cavity can be accomplished by adjusting the depth and angle of the support rod.

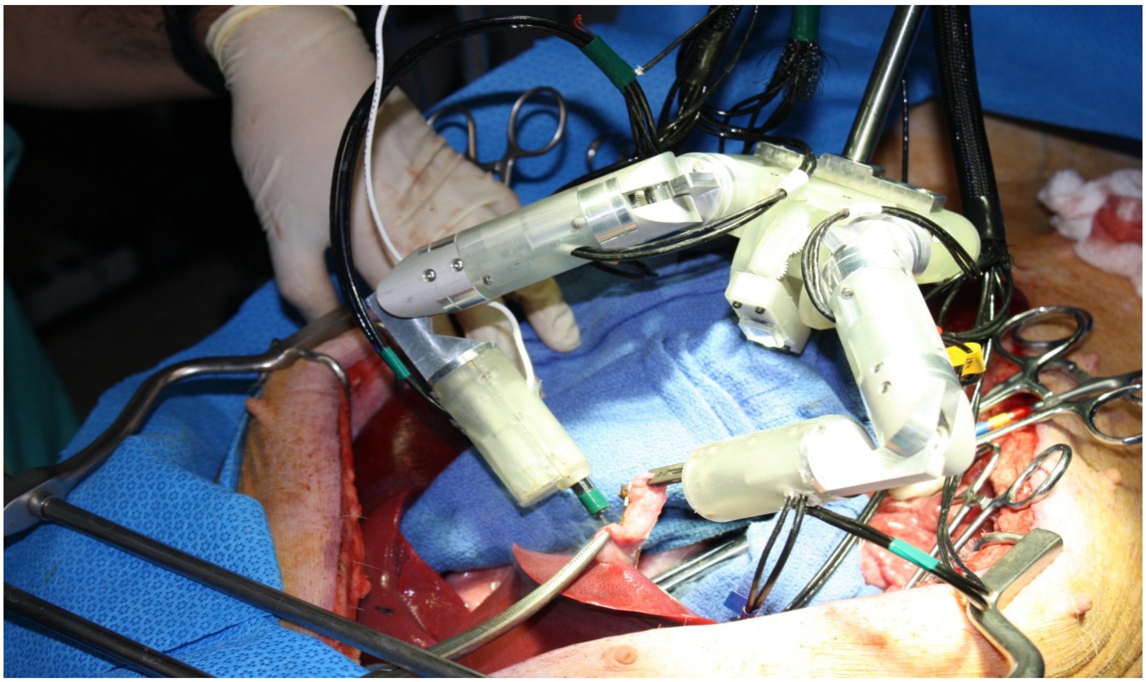

Figure 3. Miniature in vivo robot (NB2.1) performing a cholecystectomy.

Each outer module of the body, shown in Figure 4, is connected to an arm at a two-degree of freedom joint. The shoulder joint links consist of a distal joint providing yaw, and a proximal joint providing pitch. Each arm consists of a two-degree of freedom rotational elbow joint. Specialized end effectors on each forearm can be interchanged to provide tissue manipulation, monopolar cautery, and intracorporeal suturing capabilities. Each outer module is connected to a center module that contains two cameras. These cameras can provide a stereoscopic visualization with panning and tilting. An ultra bright LED is also contained in the center module to provide on-board lighting. The robot joints are independently controlled using a proportional-integral-derivative (PID) control method, with actuation provided by coreless permanent magnet direct current motors with magnetic encoders. These motors are housed within the arms and body of the robot.

The multi-functional robot platform has been prototyped tested in four non-survival cholecystectomies in a porcine model at the University of Nebraska Medical Center. All experimental protocols were approved by the Institutional Animal Care and Use Committee (IACUC). The robot was supported above the animal using the external support assembly described previously. For these procedures, a large transabdominal incision was made to provide access to the peritoneal cavity due to the size of the robot. The robot was then positioned within the proper workspace for performing a cholecystectomy. The surgeon controlled the robot from the control console located remotely within the operating room. The procedure was then performed similarly to a standard laparoscopic cholecystectomy. The grasper end effector was extended to grasp the cystic duct and lifted while the cautery end effector performed tissue dissection. This stretch and dissect task was performed iteratively until a full cholecystectomy was completed. Stapling of the cystic duct and supplementary retraction were performed using standard laparoscopic tools.

Figure 4. Separated robot outer arm modules.

Currently, improvements are being made to the NB2.1 robot design to improve performance without changing the kinematics of the robot. First, heat sinks and thermocouples are being added to the motors housed in the robot. These thermocouples will allow for temperature monitoring of the motors, allowing for shutoff before permanent motor damage occurs. Further, the housing of the motors are being changed to a “clamshell” design to eliminate the twisting required for the current assembly method of the robot. This method should provide a tighter motor fit and decrease the potential for twisting or disconnection of the ribbon cables to the motors. Further, the metal gears in the gripper attachment are being changed to plastic to electrically isolate the gripper from the electronics of the robot. This should help reduce the potential for the cautery tools to interfere with the manipulation of the robot through direct conduction with the robot grippers.

Control Interface

A new control and interface system was developed for the full mobility manipulator robots. The major changes between the old system and the new system are the changes in the hand-held controllers, PID control algorithms, programming, and user interface. The surgeon now controls the robot using two Phantom Omni controllers (SensAble) as shown in Figure 5. The improvement over the old controllers is that these hand-held haptic controllers allow the surgeon to feel the limits of the workspace and to feel collisions between the two robotic arms. This allows the surgeon to be better immersed into the virtual surgical field. Additionally, the controllers can be locked into place anywhere in their workspace. This means that the surgeon can lock the controllers and walk away and when the he returns the controllers will be in the same place as when he left.

The PID control algorithms that control the robot motors have been updated to include both position and current feedback. The addition of current feedback protects the motors from being overdriven to the point of failure. By reading the amount of current going through the motor and limiting it, the motor life can be protected. Further, an entirely new control program was developed to address several concerns from the old program. Simultaneously, the graphical user interface for the control program was updated and is shown in Figure 6. These changes allow the program to run faster, be modified more easily, and to communicate with the user more efficiently.

Figure 5. To control the robot, the surgeon manipulates two Phantom Omni haptic controllers.

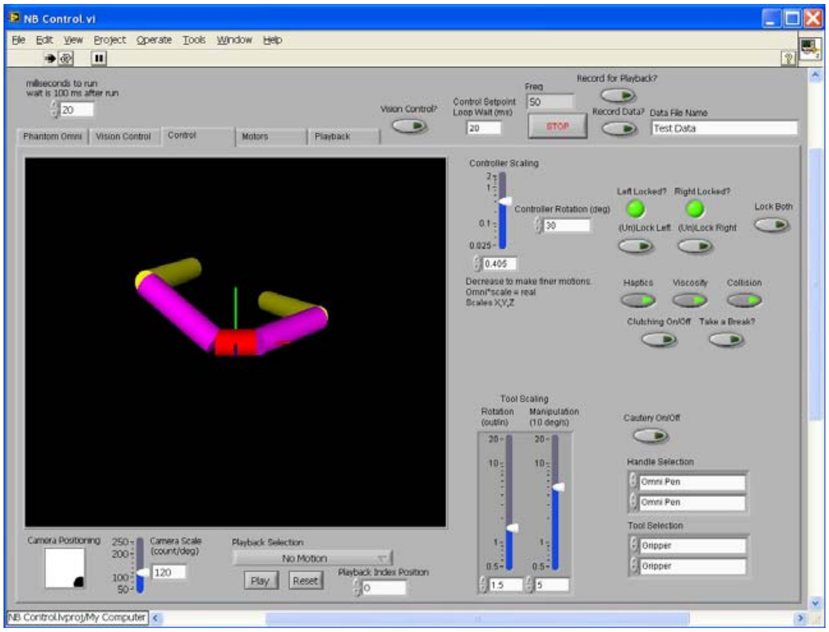

Figure 6. Updated Graphical User Interface (GUI) for the full mobility robots.

Stereoscopic Visualization

A stereoscopic visualization system is being developed for the robot [6]. The system consists of two main subsystems. The first subsystem consists of the two CMOS cameras that are mounted to central body of the *in vivo* miniature robot. The cameras can be panned and tilted to provide an adjustable viewpoint throughout a surgical procedure. Each cameras feeds live video to the monitors, where the video is reflected through a series of mirrors to surgeon. The screens and the mirrors make up the stereoscopic display subsystem, and are housed inside of a stereoscopic box. The combination of the placement of the cameras and mirrors allows for stereoscopic vision.

The cameras are placed and angled to give depth perception comparable to what a human would have focusing on an object from one meter away. Humans have depth perception because our eyes are approximately 64 millimeters away from one another, this displacement allows our eyes to see two different images, which our brain then processes and combines into one image. The cameras work in the same way. Based on the limiting dimensions of the workspace, the cameras are placed approximately 12.9 millimeters apart and angled inward at a 2.1 degree angle. These values were found using proportionality laws and similar triangles.
The stereoscopic display subsystem is shown in Figure 7. The two monitors are placed vertically at the rear of the rectangular box, providing live video from the left and right cameras, respectively. A set of mirrors is used to feed the live video from each monitor to the surgeon. One mirror is placed directly in front of each monitor in the front corners of the stereoscopic system at a 45 degree angle to the monitors. The second, smaller mirror, is placed in the center of the system and parallel to the larger set of mirrors. Two sets of mirrors are necessary to flip the image twice, so the image that is processed by the brain is the original image and not a reflection.

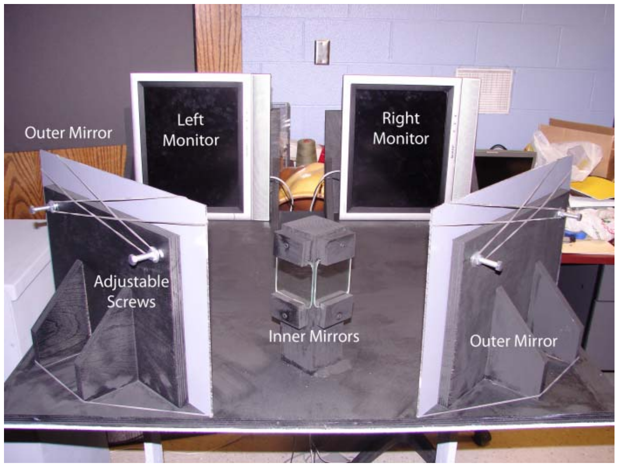

Figure 7. Stereoscopic display subsystem for multi-functional robot.

These mirrors can sit at any angle to the screens as long as they remain parallel to each other, if they do not remain parallel to each other the viewer will encounter keystone distortion, this type of distortion occurs when the image is stretched resulting in one side appearing larger and the other appearing smaller [25]**.** This distortion is exaggerated because it occurs in both the right view and the left view. This distortion of the images reduces the acuity and quality of the images, so it is essential that they remain parallel in this type of stereoscopic viewer. To compensate for any level of dissimilar angles, levels of adjustability are placed on all of the mirrors. Three adjustable screws sit behind each of the mirrors, allowing the user to correct for distortion in the image.

The smaller set of mirrors are placed adjacent to one another so the image can be centered on the mirrors at the same distance apart as the human eyes. The viewer places their eyes in line with the smaller set of mirrors of focuses on the image. The left camera feeds the video information through the left set of mirrors and this information in processed by the left eye, while the right cameras feeds the video through the right set of mirrors and is processed by the right eye. The brain then processes the different images from the two cameras and to create one image, providing the viewer with the perception of depth.

The stereoscopic visualization system with haptic technology was successfully used in non-survival animal procedures. Surgeons successfully used the entire system to complete the task of suturing. The system accurately gave the surgeon perception of depth. The surgeon noted that the stereoscopic visualization system was of significant benefit in this situation. While using this robot, it helped the surgeon accurately position the end effectors. This system will be used in more complex procedures in the near future.

Modular Wireless Mobile Robot

Circuit boards and cautery have been successfully tested for the modular wireless mobile robot platform. The robot design is being adjusted to fit the components into the robot's modular payload housing. Current research is also focused on evaluating the staple/clamp arm and its ability to provide enough pressure to stop blood flowing through a vessel. These evaluations using Finite Element Software are being compared with the previously completed ex vivo and in vivo test results of the biopsy grasper. The tissue interaction during a liver biopsy is also being investigated. Work is also being done to create a soft-tissue model to evaluate the performance of end effectors such as the biopsy grasper. Other payload variations for surgical task assistance are in the conceptual stages.

Task 2: Development of an "easy to carry" relay system and remote user interface

Wireless control and video capabilities are being developed for integration with the manipulator robots. The control design allows the robot to be controlled through either a graphic user interface, or remotely with the previously described surgeon console using existing wired and wireless local Ethernet network. An overview of the combined system for controlling the in vivo robot remotely is shown in Figure 8.

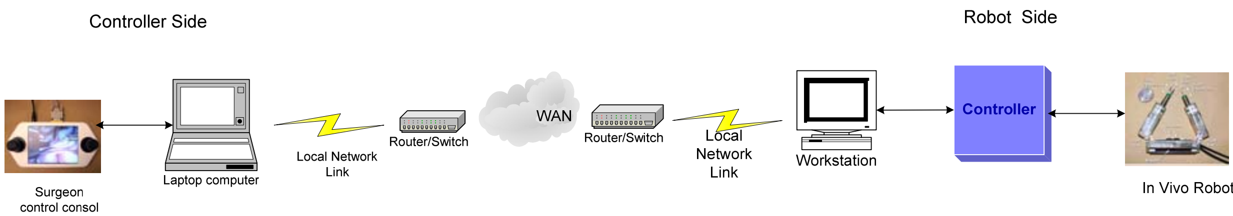

Figure 8. Overview of remote user interface system.

The system software uses a layered design. The main benefit of a layered software design is the isolation of the different levels of control and communication. Low level control of robot actuators and cameras as well as the surgeon control console are in the lowest software layer. Communication, the graphical user interface, and user management is at a different, higher layer. The layers communicate through messages, which makes the design more portable to different robots. TCP/IP protocol is used for the control messages between the robot and the control station. The video from the robot camera is streamed through an embedded plug-in for VLC player using asf/wmv encoding with 200ms buffering.

A benchtop test of the remote user interface was performed between the surgeon console, located at the University of Nebraska Medical Center (UNMC) in Omaha, Nebraska, and the robot located at the University of Nebraska-Lincoln (UNL), in Lincoln, Nebraska. Results showed an average control delay of 251 ms while performing the remote control. The average local control delay of the robot using a loopback IP address is about 91 ms. For this test, the control station was connected through a wireless 802.11g to the UNMC wireless network, while the robot was connected through to a 802.2 wired network to UNL's network.

Difficulty has been encountered in ensuring quality video is being made available to the surgeon. A significant challenge has been to consistently provide high quality video (in terms of resolution and frame rates) with low enough latency that robot motion commands, from the surgeon, correspond spatially and temporally with the robot's actual motion. This latency stems primarily from two sources: the off-the-shelf video frame grabber needed to convert the analog image to digital, and the video buffer employed by the off-the-shelf video playback software, which buffers frames to provide smooth playback. Additional manipulations, provided within the approved no-cost extension, are necessary to finalize the user datagram protocols (UDP) for use with the remote user interface and relay station. Once the digital image sensor is integrated with the in vivo robot, the relay system and remote user interface will be updated to capture and transmit the digital image directly, rather than using the frame grabber. This will eliminate the analog to video conversion latency and help to reduce latency in the video transmission, ultimately making the system more surgeon user friendly. If further latency reduction is required, portions of the playback software will need to be rewritten to reduce buffering. This may result in increased video jitter under some network conditions, but will eliminate the current frame buffer latency.

Other work has focused on developing a method of controlling the video parameters of the digital imaging board which utilizes the Omni Vision OV2640 imaging chip with the Omni Vision OV550 camera bridge processor. The resulting software solution enables direct access to the imager board's memory registers and supports control actions such as changing the output format, i.e. choosing image compression algorithm, setting frame size and refresh rates, and enabling/disabling the digital signal processing functions offered by the imaging chip. The image processing functions include automatic or manual white balance control and the adjustment of the image contrast and brightness. The second major focus resulted in the development of a prototype stereoscopic vision system to be developed and implemented. The system consists of two, 2-MegaPixel Logitech C905 webcams, a polarized ED monitor (Hyundai, model W220s) and a computer with the MATLAB environment installed. Frames from the webcams are acquired using MATLAB's Image Acquisition Toolbox and interlaced to produce a full-color stereoscopic video stream which allows end-users to perceive the true depth of the observed scene in real-time.

Task 3: Develop procedures and techniques for military use of in vivo robots

Continued benchtop experiments elicited several potential military and clinical applications including immediate exploration, diagnosis, triage, stabilizing treatment, and transmission of medical information. Field deployable in vivo robots, with minimal size and weight, have the capability to positively impact both forward and noncombatant care environments through decreased wound infections, pain, recovery time, and adhesions.

Ongoing testing has indicated that we are able to effectively grasp and manipulate tissues with increased dexterity, which has allowed successful robotic abdominal exploration and blood vessel ligation. Abdominal surgical procedures performed by the most recent miniature robotic prototype have produced liver, splenic, and visceral artery bleeding. Subsequently, we have been developing various robotic devices including clamps, cautery, and clips to control blood loss. Upcoming animal experimentation, slated to occur in March 2010, will accommodate additional device manipulation and testing necessary to mitigate and prevent liver, splenic, and visceral artery bleeding. Continued bench top experimentation will implement as well as determine the efficacy of clamps, cautery, and/or clip devices within the robotic prototype to control blood loss.

Task 4: Integration and testing

The above sub-systems will be integrated into a deliverable system. The above tasks build on previous preliminary studies performed by this investigative team. Large aspects of Tasks 1 and 2 have been demonstrated in clinical environments on animal models. A continued challenge of the work, to be performed within the ongoing no-cost extension period, will be to make these systems function in forward situations. Subsequently, much work has been done to date including the design, construction, and testing of more than five robot prototypes. Additional time allows for the continued development and testing needed to incorporate the outcomes of Tasks 1-3 above.

Key Research Accomplishments

- Four full mobility manipulator robots have been built and demonstrated in benchtop testing and non-survival animal model surgeries.
- PID controllers have been developed for the full mobility manipulator robots allowing for real-time position tracking of a master manipulator. This has greatly improved the speed and dexterity of the robot.
- Monopolar electrosurgery capabilities have been introduced with the manipulator robots. This significantly improves performance compared to previous heat element cautery methods.
- Stereovision display systems have been developed for the robot.
- A stereo camera circuit board has been designed, built and tested for the manipulator robots.
- The video from the manipulator robot cameras have been recorded wireless using RF transceivers.
- Circuit boards for the modular wireless robot platform have been tested and the platform design is being adjusted to allow for implementation.
- A graphical user interface has been developed to control the prototype planar manipulator robots through the Ethernet.
- The user interface for the prototype planar manipulator robots has been tested through wired and wireless networks. Software has been developed to control the camera and image settings from the manipulator robots through the Ethernet.
- Finite Element Analysis of the biopsy grasping mechanism for the wireless mobile robot is being performed and compared with previous in vivo and ex vivo test results.
- A model to evaluate the performance of robotic end effectors (such as biopsy) when cutting organ tissue is being developed.

Reportable Outcomes

Refereed Journal Publications:

Lehman, A.C., Dumpert, J., Wood, N.A., Visty, A.Q., Farritor, S.M., Varnell, B., Oleynikov, D., "Natural Orifice Translumenal Endoscopic Surgery with a Miniature *In Vivo* Surgical Robot (Video)," *Surgical Endoscopy*, 23(7), 2009.

Canes, D., Lehman, A.C., Farritor, S.M., Oleynikov, D., Desai, M.M., "The Future of NOTES Instrumentation: Flexible Robotics and In Vivo Minirobots," Journal of Endourology, 23(5): 787-92, 2009.

Shah, B.C., Buettner, S.L., Lehman, A.C., Farritor, S., Oleynikov, D., "Miniature In Vivo Robotics and Novel Robotic Surgical Platforms," Urologic Clinics of North America, 36(2): 251-263, 2009.

Lehman, A.C., Tiwari, M.M., Shah, B.C., Farritor, S.M., Nelson, C.A., Oleynikov, D., "Recent Advances in Robotic Manipulators and Miniature In Vivo Robotics for Minimally Invasive Surgery," Journal of Mechanical Engineering Science, Submitted.

Lehman, A.C., Wood, N.A., Farritor, S.M., Goede, M.R., Oleynikov, D., "Dexterous Robot for Single Incision Advanced Minimally Invasive Surgery," *Surgical Endoscopy*, Submitted.

Qadi, A., Goddard, S., Huang, J., Farritor, S., "On Providing Performance Guarantees of an Autonomous Mobile Robot," International Journal of Robotics and Automation, Submitted.

Tiwari, M.M., Reynoso, J.F., Lehman, A.C., Tsang, A.W., Farritor, S.M., Oleynikov, D., "In Vivo Miniature Robots for Natural Orifice Surgery: State of the Art and Future Perspectives, World Journal of Gastrointestinal Surgery, Submitted.

Wortman, T.D., Strabala, K.W., Lehman, A.C., Farritor, S.M., Oleynikov, D. "Laparoendoscopic Single-Site Surgery using a Multi-Functional Miniature In Vivo Robot," The International Journal of Medical Robotics and Computer Assisted Surgery, Submitted.

Refereed Conference Publications and Presentations:

Zhang, X., Lehman, A.C., Nelson, C.A., Farritor, S.M., Oleynikov, D., "Cooperative Robotic Assistant for Laparoscopic Surgery: CoBRASurge," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, St. Louis, MO, October 2009.

Dumpert, J., Lehman, A.C., Wood, N.A., Oleynikov, D., Farritor, S.M., "Semi-Autonomous Surgical Tasks Using a Miniature *In Vivo* Surgical Robot," *Engineering in Medicine and Biology Conference*, Minneapolis, MN, September 2009.

Bornhoft, J.M., Strabala, K.W., Wortman, T.D., Lehman, A.C., Oleynikov, D., Farritor, S.M., "Stereoscopic Visualization and Haptic Technology Used to Create a Virtual Environment for Remote Surgery," *ASME 2010 World Conference on Innovative Virtual Reality*, Ames, IA, May 2010, *Submitted.*

Book Chapters:

Farritor, S.M., Lehman, A.C., Oleynikov, D., "Miniature *In Vivo* Robots for NOTES," *Surgical Robotics – Systems, Applications, and Visions*, Submitted.

Medical Conference Publications and Presentations:

Lehman, A.C., Wood, N.A., Farritor, S.M., Goede, M.R., Oleynikov, D., "Dexterous Robot for Single Incision Advanced Minimally Invasive Surgery," *The Society of American Gastrointestinal and Endoscopic Surgeons*, Phoenix, AZ, April 2009.

Wortman, T.D., Strabala, K.W., Lehman, A.C., Farritor, S.M., Oleynikov, D. "Laparoendoscopic Single-Site Surgery using a Multi-Functional Miniature In Vivo Robot," *Minimally Invasive Robotic Association*, San Diego, CA, January 2010.

Conclusion

Our long-term goal, to use image-guided miniature robots to convert open and laparoscopic surgeries to the NOTES approach, can be realized through the development of a family of in vivo robots. Completion of the current statement of work is a critical first step toward this effort as it builds on previous successes and focuses on developing an image-guided robot capable of provisions of basic diagnosis and triage.

Initial testing has indicated that the default imager settings, e.g., hue and saturation, are not ideal for surgical environments. Supporting documentation and application software from the manufacturer for this sensor are incomplete in order to determine the imaging settings that will yield optimal video for surgical applications Subsequently, additional in vivo experimentation is necessary to design an apparatus and protocols that produce idyllic in vivo imager settings. Continued development of an "easy to carry" relay system and remote user interface is necessary to enable the transference of real-time video to perform innovative robotic diagnosis and intervention in forward environments. Difficulties with regard to video latency, multicasting, reliability and congestion control issues require additional manipulation of UDP to ensure high quality video with low enough latency that robot motion commands from the surgeon correspond spatially and temporally with the in vivo robot's actual motion. Several functional prototypes capable of tissue manipulation, abdominal exploration, and blood vessel ligation have been developed, but require additional device manipulation and testing to mitigate and prevent liver, splenic, and visceral artery bleeding. Continued bench top experimentation will implement as well as determine the efficacy of clamps, cautery, and/or clip devices within the robotic prototype to control blood loss. Additional time provided by the no-cost extension period allows for the continued development and testing needed to incorporate the outcomes of Tasks 1-4 above. This revolutionary robotic technology has demonstrated its applicability and benefit in natural orifice and single incision minimally invasive surgical procedures. Such procedures are virtually impossible to perform without the design and creation of new tools like our miniature robots.

The small, in vivo robots developed in this study may enable lifesaving diagnosis and triage in more forward military environments. The second phase of this project will focus on continued in vivo testing as well as the acquisition of regulatory approval. The portability and survivability of our technology in forward, rugged situations is a substantial challenge to be met; we plan continued trauma model testing and prototype development to meet this challenge. Project success will have a direct impact on combat medical care, thus matching TATRC's Research Area of Interest B, Combat Casualty Care Research Program. The new robotic technology will also be useful in many other levels of military medical care including level five treatment and stateside facilities as well as significantly impacting the application of NOTES and single incision laparoscopic surgery everywhere.

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